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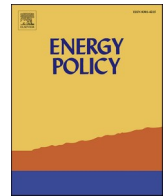
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Understanding the socio-technical nexus of Nordic electric vehicle (EV) barriers: A qualitative discussion of range, price, charging and knowledge

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ABSTRACT

Electric vehicles are perceived as a key alternate to internal combustion engine vehicles for a transition to a decarbonized society. However, this transition towards the electrification of transport has not made equal progress globally, and faced several impediments to consumer adoption of EVs across the Nordic region and beyond. While there has been a multitude of reasons provided in the literature, we aim to characterize the barriers that remain to electrification today, as well as their perceived interconnections and futures. To provide insight into this query, the authors conducted 227 semi-structured interviews with transportation and electricity experts from 201 institutions across seventeen cities in Denmark, Finland, Iceland, Norway, and Sweden. The qualitative results and consequent cluster analysis show that common barriers like range, price and charging infrastructure continue to persist, despite technological advancements over the recent years. At the same time, results also show that barriers are highly interconnected and are commonly connected to consumer knowledge and experience. The article concludes with a discussion of policy implications of the findings and potential future research.

1. Introduction

Electric vehicles (EVs) are seen as an important tool in the socio-technical transition towards the decarbonization of transportation, along with capturing other co-benefits associated with local health emissions, reduced oil dependency and noise pollution (Egbue and Long, 2012; Sovacool and Hirsh, 2009). The global importance of EVs has been legitimized in recent years, at a governmental level, with most major economies setting EV penetration targets in the short (2020), medium (2030) or long term (2050), and at industry level, with most automotive manufacturers announcing the introduction of one or several EV models by 2020; which has seen EV market surpassing the 2 million global penetration milestone in 2016 (IEA, 2017). Nonetheless, while EVs have continued to make technological advancements and adoption progress, they continue to face a variety of impediments and have not yet made a substantial mark on the global vehicle fleet, accounting for only 0.2% of the total passenger vehicle fleet by the end of 2016 (IEA, 2017). As a result, there has been a lot of focus, particularly in academic spheres,

with a wide variety of articles investigating the barriers to EV adoption, aiming to explore the lag in EV sales as compared to the climate and health benefits they purport, with a selected few articles shown in Table 1 (which are from both the perspectives of experts as well as consumers).

The central barriers identified in the academic literature are mostly technical or economic. Indeed, common across the literature has been a focus on range, price and charging infrastructure as the techno-economic elements impeding wide-scale EV adoption. For example, limitations in battery capacity constrains the driving range of an EV and the simple increase of the physical size of the battery is not a sustainable or cost-effective solution (Neubauer et al., 2012), and likewise, incentives to address battery limitations may not be cost effective either (Silvia and Krause, 2016; Noel and Sovacool, 2016). Alternatively, the continued improvements on energy density of vehicle battery packs still necessitates substantial scientific and technological development and faces limited ceilings of development (Thackeray et al., 2012).

Non-technical elements, however, such as social and business

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Table 1
Summary of literature regarding EV barriers.

Author	Citation	Year	Method	Central Barriers
Sovacool et al.	Sovacool and Hirsh (2009)	2009	Qualitative literature review	Price, consumer knowledge, institutional inertia
Hidrué et al.	Hidrué et al. (2011)	2011	Survey	Range, Charging Time, Price
Axsen & Kurani	(Axsen and Kurani, 2011)	2011	Survey	Range, Public charging, Immature Technology, Price
Egbue & Long	Egbue and Long (2012)	2012	Survey	Range and price
Flamm & Agrawal	(Flamm and Agrawal, 2012)	2012	Focus Group	Price, worse technology, charging infrastructure
Graham-Rowe et al.,	(Graham-Rowe et al., 2012)	2012	Consumer Test Drive and Interview	Price, performance, range, aesthetics, symbolic value
Steinheilber et al.	(Steinheilber et al., 2013)	2013	Expert Interview	Government policy, charging infrastructure, business models
Schuitema et al.	Schuitema et al. (2013)	2013	Survey	Range, consumer perceptions
Sierzchula et al.	(Sierzchula et al., 2014)	2014	Regression Model	Price (subsidies) and charging infrastructure
Rezvani et al.	Rezvani et al. (2015)	2015	Literature Review	Consumer perceptions & knowledge, price
Biresselioglu, Demirbag Kaplan, and Yilmaz	(Biresselioglu et al., 2018) ,	2018	Literature Review	Charging Infrastructure, Price, Battery technology, consumer trust, grid integration, and vehicle model availability

practices or political interests, have also been identified as barriers to electrification, these being more complex to overcome ([Sovacool and Hirsh, 2009](#)). In this light, the literature has more recently tended to focus on consumers, often with limited experience with EVs, to explain barriers in EV adoption ([Rezvani et al., 2015](#)). As such, much of the current literature looks to explain the barriers that individual consumers encounter when purchasing EVs, either using qualitative methods ([Egbue and Long, 2012](#); [Schuitema et al., 2013](#); [Franke and Krems, 2013](#)), or also commonly, choice experiments to analyze willingness-to-pay for electric vehicles ([Jensen et al., 2013](#); [Noel et al., 2019](#); [Hidrué et al., 2011](#)).

So, while the literature identified barriers that are mostly technical or economic, there is also identification that consumer's behavior, knowledge and perceptions play a role in EV adoption. For example, a recent sociotechnical review of EV barriers and motivators acknowledged a myriad of technical barriers that connect to different levels of society, such as decision-makers and individual ([Biresselioglu et al., 2018](#)), though the nuances of the interconnections between barriers, consumers and society can still be further developed.

This paper aims to explore an assortment of the barriers that EVs face as well as defining particularly the nexus that exists between the major techno-economic and consumer knowledge barriers, a nexus that we have termed 'socio-technical' ([Geels et al., 2018](#)). As compared to the literature presented in [Table 1](#), this paper adds four novel contributions to the literature. First and foremost, the authors conducted 227 semi-structured interviews with participants from 201 institutions across seventeen cities in the five Nordic countries, whereas the sole previous expert interview focused on the UK and Germany, had a much

smaller sample size (13 compared to 227), and is potentially outdated given how fast EV technology develops. Secondly, this paper is the first to develop a nexus of barriers and show the interconnectedness of a large variety of barriers. Thirdly, the results identify topics considered by experts to be either no longer or will soon not be a barrier. Fourthly, this paper offers a first to attempt to characterize a comprehensive perspective of EV barriers, and discusses a total of 53 barriers, some of which are not previously discussed in the literature, especially beyond those at the top of the list (such as range, price, or charging infrastructure).

While the interviewees define electric vehicles, experts generally referred to either light private passenger battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV), but also accounted of other forms of electric mobility such as fleets and public transportation. Selected experts were from national government ministries, agencies, and departments; local government ministries, agencies, and departments; regulatory authorities and bodies; universities and research institutes; power transmission, distribution and supply utilities; automobile manufacturers and car dealerships; private sector companies; and industry groups and civil society organizations. These experts were found using a variety of methods, including personal networks, searching by expertise in academic and professional channels, and the snowball method to further increase the completeness of our interviews. We then analyze this dataset using a mix of methods including qualitative analysis and cluster analysis.

The research is placed in a Nordic context as these nations have traditionally been positioned at the top various indicators in favor of EV diffusion (for example, that they can afford EVs, often considered an expensive technology), as well as being recognized for pushing aggressive decarbonization agendas within the energy and transport sectors ([Sovacool, 2017](#)). For example, by 2016, Norway and Sweden being the first and third nations in terms of national EV market share, with 29% and 3.4% respectively ([IEA, 2017](#)); or Norway and Denmark offering the highest electric vehicle purchase subsidies ([Hertzke et al., 2017](#)). The aim is to investigate and reflect how even within such advanced economies, EVs still face a multitude of barriers, and many of these include both technical and non-technical elements. Therefore, this research serves as a means of reference for other nations aiming to endeavor in EV technology as a tool within their decarbonization agendas.

2. Conceptual approach and research design

To help understand the barriers facing EVs, the study largely views the related transport and electricity infrastructure connected to EVs as a "socio-technical system"—looking at more than just the technical aspects to how it is part of and influences society.

2.1. Conceptual approach: socio-technical systems

The term sociotechnical system finds its origin rooted in multiple disciplines and approaches. One of the best known is Thomas Hughes's work on the history of the electric utility system, wherein he argues that the generation, transmission and distribution of electricity occurs within a technological system that extends beyond the engineering realm ([Thomas Parke Hughes, 1993](#)). Such a system is understood to include a "seamless web" of considerations that can be categorized as technical, economic or financial, political, environmental, and social, making it "sociotechnical" ([Thomas P. Hughes, 1986](#)). In other words, the concept of a sociotechnical system helps reveal that technologies, such as electricity grids and EVs, must be understood in their societal context, and that the different values expressed by inventors, producers, managers, regulators, and consumers shape technological change all in their own way. System builders, it follows, must overcome a complex milieu of sociotechnical obstacles to reap benefits. A salient insight from the sociotechnical approach is its focuses on the interrelationship of linkages between elements and co-evolutionary processes, e.g. that a system

never stands on its own but is nested in other equally complex socio-technical systems. Fig. 1 offers an illustration of the sociotechnical system that surrounds modern, conventional, car-based land transport.

The study takes a sociotechnical approach, as this approach encourages scholars to look beyond single dimensions without losing the complexity of the system and doing injustice to the many interactions and relationships that shape it. Specifically, we investigate EVs across various sociotechnical categories including range, price, charging infrastructure, consumer knowledge, and other barriers. In laying out the following interconnected barriers, it is not our intent to suppose that demarcations between “technical,” “financial,” “socio-environmental,” and “behavioral” dimensions really exist in distinct, separate classes. The entire point of the sociotechnical systems approach is that such impediments are seamlessly interconnected; dividing the “social” from the “technical,” or even the “economic” from the “environmental” is counterproductive and dangerous, since it misses the point that such factors exist in an interstitial and interdependent network. In other words, it is a heterogeneous combination of sociotechnical factors that determine whether EVs technologies will achieve widespread acceptance, or face consumer rejection. Nonetheless, the different analytical categories operate as a useful heuristic for focusing the discussion.

2.2. Research design: qualitative expert interviews

To explore the socio-technical barriers surrounding electric mobility in a more holistic and qualitative manner, the authors relied primarily on original data collected through semi-structured research interviews. This methodology was applied on a regional context taking the five Nordic countries as place of study, since it is recognized that these countries have traditionally had progressive push of climate, energy and transport policy agendas emerging as leading nations in electric vehicle uptake (Norway), or pioneers of wind energy (Denmark), or geothermal energy (Iceland).

Semi-structured interviews refers to the collection of the data for this study, by asking semi-structured questions to participants. This methodology allows the authors to have guidance and flexibility, by asking a set of fixed questions to then, create a conversational channel of information-gathering, allowing space for spontaneous responses that add depth and in some instances unforeseen narratives to the research (Harrell and Bradley, 2009). These semi-structured form of interviewing is suitable when the objective of the research is to understand complex elements and their intersection with perceptions, beliefs, and values (Yin, 2003). Lastly, the authors selected this research method as it

allowed for novel and up-to-date data (at the time of the interview) which was not available in other formats, since official documents can take months or even years to be published.

The authors conducted 227 semi-structured interviews with participants from 201 institutions across 15 cities in the five countries of Denmark, Finland, Iceland, Norway and Sweden from September 2016 to May 2017. Those interviewed were selected to represent the diverse array of stakeholders involved with transport technology, policy and practice, and included members of:

- National government ministries, agencies, and departments including the Ministry of Industries & Innovation (Iceland), Ministry of Environment and Energy (Sweden), Ministry of Finance (Finland), and Ministry of Taxation (Denmark);
- Local government ministries, agencies, and departments including the Akureyri Municipality (Iceland), City of Stockholm (Sweden), Aarhus Kommune (Denmark), City of Tampere (Finland), City of Oslo (Norway), and Trondheim Kommune (Norway);
- Regulatory authorities and bodies including the National Energy Authority (Iceland), Danish Transport Authority, Icelandic Transport Authority, Helsinki Regional Transport Authority (Finland) and Trafi (Finland);
- Universities and research institutes including the University of Iceland, Swedish Environmental Institute, DTU (Denmark), Aalborg University (Denmark), VTT Technical Research Centre (Finland), NTNU (Norway), and the Arctic University of Norway;
- Electricity industry players such as ON Energy (Iceland), E.ON (Sweden), Vattenfall (Sweden), Energinet (Denmark), DONG (Denmark), Fingrid (Finland), Elenia (Finland) and Statnett (Norway);
- Automobile manufacturers and dealerships including the BMW Group (Norway), Volvo (Sweden), Nissan Nordic (Finland), Volkswagen (Norway), and Renault (Denmark);
- Private sector companies including Siemens Mobility (Denmark), Nuvve (Denmark), Fortrum (Finland), Virta (Finland), Clever (Sweden), Nordpool, (Sweden), Norske Hydrogen (Norway), Microsoft (Norway) and Schneider Electric (Norway);
- Industry groups and civil society organizations such as the Danish Electric Vehicle Alliance (Denmark), Finnish Petroleum and Biofuels Association, Tesla Club (Finland), Power Circle (Sweden) and the Norwegian Electric Vehicle Association.

Interviews lasted generally between thirty and 90 min in their

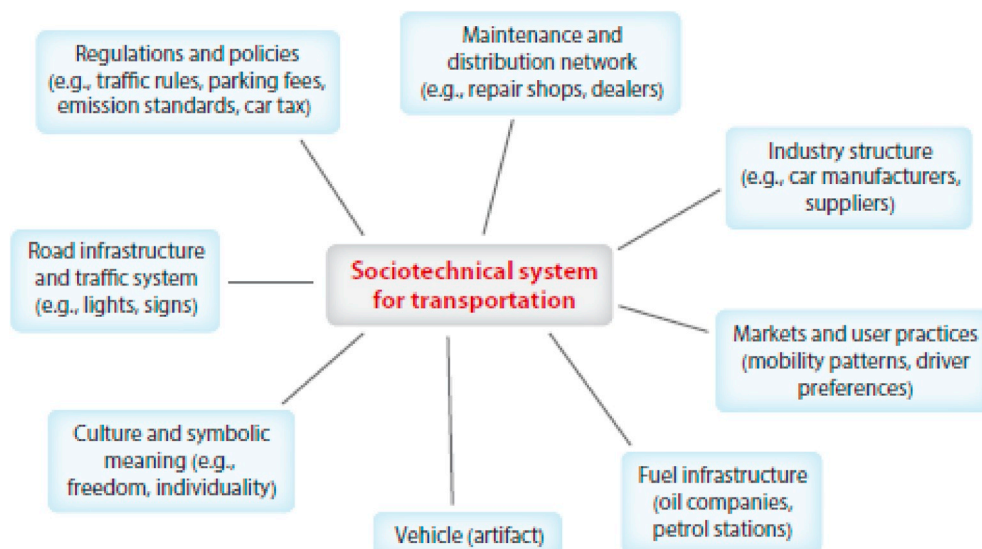


Fig. 1. Viewing automobiles and mobility as a socio-technical system Source (Sovacool et al., 2018a,b).

duration, and participants were, among others, asked the question: “What are the barriers that electric vehicles currently face?”. The following context in the interview was developed according to the background of each respondent. Participants were not prompted for responses and were allowed to provide answers as long or as detailed as they wished. Likewise, we did not define any terms and allowed broad discussion of each topic, meaning some experts discussed electric vehicles in the context of personal transportation, but also other types of vehicles, such as buses or heavy-duty trucks. Each expert encounter was recorded, with the authorization of the respondent, and then fully transcribed. Each participant was also given a unique respondent number (which we refer to whenever presenting interview data).

Admittedly, the nonrandom sample relied upon for primary data is limited in several ways. For example, interviews were constricted to researchers that spoke English, moderated by locations visited, and may suffer from potential selection bias. Likewise, the data from the interviews is presented here as *anonymous* to encourage candor and prevent retaliation. Although participants were therefore guaranteed anonymity, Appendix I offers a high-level summary of the interview respondents. Finally, the research was *grounded* in the sense that we

commenced our project without any preformed hypotheses (Geertz, 1973; Strauss and Corbin, 1990). The reasoning behind this was that we maintain a grounded approach helps minimize interpretative bias caused by researchers trying to force responses into preset cognitive frameworks (Blaikie, 2000; Cook and Campbell, 1979).

After collection of the interview data, each interview was subsequently fully transcribed, and then coded in NVIVO. The data was coded with grounded theory in mind, meaning that the coded themes for each discussed topic were not predetermined, but based on the data available. Below we present quotes and the themes which were coded in NVIVO. In addition to the descriptive analyses, we also utilized a cluster analysis for Fig. 2, shown below, based on the coded similarity between each of the coded themes across our interviews. In other words, to what extent a theme returns in other interviews and with which other coded themes. This analysis was conducted by using NVIVO, and it utilizes a Jaccard's coefficient of similarity (Jaccard, 1901), a metric for comparing shared similarity between two disparate data sets, implying a larger value has a larger share of coding similarity, i.e. the themes were more closely related.

Finally, our qualitative approach does possess shortcomings. The

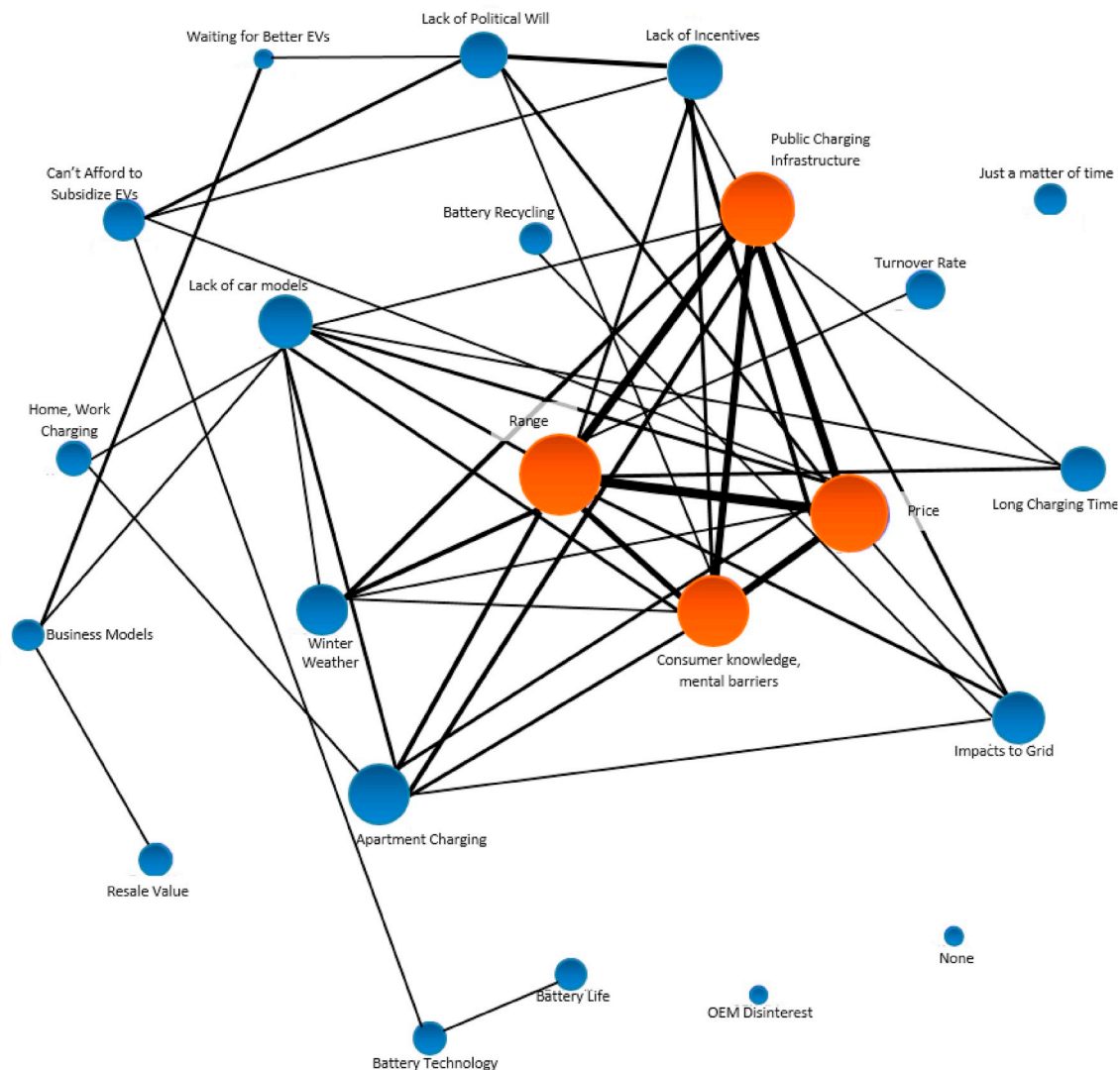


Fig. 2. Cluster analysis of EV barriers, with proposed nexus demarcated by the color orange (for identification). Circle size shows respondent frequency (showing only those discussed by 4% or more of respondents), line thickness based on Jaccard's coefficient of similarity ($J \geq 0.1$). The figure does not show the entirety of barriers displayed on Table 2. Note: OEM = original equipment manufacturer. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

qualitative aspect of interview responses makes them difficult to code and answers understandably varied for each participant. Some respondents may have provided socially desirable responses, telling us what they think we wanted to hear. Others could have deliberately given answers that they thought would sway the outcome of the study in their favor. Inaccuracies could also arise due to poor recall and memory of the interviewee (Kroes and Sheldon, 1988). We have attempted to minimize these shortcomings by validating their findings with a secondary method, that of a literature review, and by triangulating responses within the sample (i.e., not presenting only minority opinions).

3. Results & discussion

We aim to present the barriers from our body of evidence in a novel way. In addition to keeping track of barriers the experts discussed for EVs, we also noted when respondents either explicitly said a certain topic was *not a barrier*, as well as when it would *soon not be a barrier*. Both of these were unprompted, as experts were only explicitly asked what is a barrier to EV deployment.

There was a wide variety of barriers to EVs suggested by the experts, with a total of 53 different categories of barriers, as summarized in Table 2. In addition to a variety in aggregate, individual experts offered many suggestions of the obstacles EVs faced, as each expert suggested on average over 4 barriers. As such, experts often weaved barriers together characterizing one barrier as dependent on another. Implicit in this is that there is not just one barrier holding back EVs, even among those who disagree which barriers are the central ones. Moreover, the barriers encompassed a variety of topics, including technical (range and impacts to grid), economic (price, consumer incentives), social (consumer knowledge, political will), business/industrial (OEM disinterest, business models), and environmental (winter weather).

Consequently, as shown in Fig. 2, a clear nexus was formed from the connections between the primary barriers (discussed by more than 25% of respondents) and even with secondary barriers (less than 25% of respondents). Here we propose the nexus of barriers comprised of range, price, public charging infrastructure, and mental barriers or knowledge. This nexus of four barriers is important because it represents both the most discussed barriers (as shown by the size of the circle), and also the most interconnected barriers (as shown by the connecting lines), implying resolution of other secondary barriers may be dependent on resolving the central four barriers in the nexus. The first three aspects of the nexus, range, price and public charging infrastructure fit squarely within the techno-economic on which the literature often focuses, and were also the three most commonly discussed barriers. At the same time, each of these were the three most commonly discussed topics for those either explicitly not a barrier or perceived to soon not be a barrier, as shown in Fig. 3. We discuss each of the four aspects of the nexus in turn below.

In addition, there is some differentiation of these barriers across the countries. In Table 3, we show how the top ten barriers are distributed across the five Nordic countries (the remaining 43 barriers had little variation and dwindling denominator, thus were omitted). Though there is relative consistency throughout these barriers, there are three notable exceptions. First, a comparatively low percent of experts in Norway mentioned price, which makes sense given their generous EV subsidies. Second, Denmark presents a special case, primarily because at the time of the interviews the Danish government had started to phase out earlier tax benefits (at the time of writing these were halted again), which explains the Danish expert's markedly higher response rate on *EV taxes* and *lack of incentives*. Also because of the low rate of concern about public charging infrastructure, which might be explained in line with leftover charging infrastructure from previous EV companies (Noel and Sovacool, 2016), and relative smaller country. Lastly, Swedish experts had a much higher response rate for *consumer knowledge* and *apartment charging*. Possibly it stems from the Swedish car market, which is heavily influenced by the presence of Volvo; both in relation to a consumer focus

Table 2

Summary of 53 barriers to EVs identified by expert interviews (n = 227).

No.	Barrier	Number of respondents	Percentage of Experts
1	Range	136	59.9%
2	Price	130	57.3%
3	Public charging infrastructure	110	48.5%
4	Consumer knowledge, mental barriers	95	41.9%
5	Apartment charging	49	21.6%
6	Lack of incentives for consumers	45	19.8%
7	Lack of car models	39	17.2%
8	Impacts to Grid	37	16.3%
9	Winter Weather	36	15.9%
10	Lack of political will	28	12.3%
11	Long Charging Time	25	11.0%
12	Can't afford to subsidize EVs	21	9.3%
13	Turnover Rate	18	7.9%
14	Home, Work Charging	14	6.2%
15	Battery Technology	12	5.3%
16	Resale Value	11	4.8%
17	Battery life	10	4.4%
18	Battery recycling	10	4.4%
19	Business Models	10	4.4%
20	Just a matter of time	10	4.4%
21	Waiting for better EV	9	4.0%
22	None	9	4.0%
23	OEM disinterest	9	4.0%
24	Charging standards	8	3.5%
25	Material Constraints	8	3.5%
26	OEM production capacity	8	3.5%
27	Battery production	6	2.6%
28	Biofuel industry	6	2.6%
29	Dealership disinterest	5	2.2%
30	Worse Performance	5	2.2%
31	Developing the 'EV Ecosystem'	4	1.8%
32	Electricity Taxation	4	1.8%
33	Public charging too complex	4	1.8%
34	Actor knowledge, willingness	3	1.3%
35	Conservative utilities	3	1.3%
36	Battery Fires & Safety	3	1.3%
37	EV availability (i.e., certain EV models not sold within country)	3	1.3%
38	Reliability	3	1.3%
39	Demand charge	2	0.9%
40	Distrust of car producers	2	0.9%
41	Increasing use of conv. electricity	2	0.9%
42	Low amounts of EVs within country's current vehicle fleet	2	0.9%
43	Business development	1	0.4%
44	Commercial vehicle constraints	1	0.4%
45	Displacing public transportation	1	0.4%
46	Heavy Transport	1	0.4%
47	Misinformation, lobbying against EVs	1	0.4%
48	No smart charging capability	1	0.4%
49	Not paying fuel, road tax	1	0.4%
50	Oil Industry	1	0.4%
51	Rather use other fuels, technology	1	0.4%
52	Tires wearing more quickly	1	0.4%
53	Well-to-wheel emissions	1	0.4%

on buying Volvo and in relation to the resulting low level of taxes on cars in Sweden, which makes consumer knowledge about EVs and a willingness to buy more important (as indicated by the attention to *price*). Regarding *apartment charging*, Swedish experts believed this to be the next big and so far unresolved challenge, with a large proportion of Swedes living in apartment buildings (see Section 3.5).

Finally, we show the frequency of each barrier discussed differentiated by the respondent's expertise (see Table A1 for further information). Similar to Table 3, we focus on the top ten barriers. While the general trend is the same across the different categories, i.e. range, price, public charging and consumer knowledge are generally among the top four most pertinent barriers, there are a few notable exceptions. For example, experts within the environmental/climate change field and the

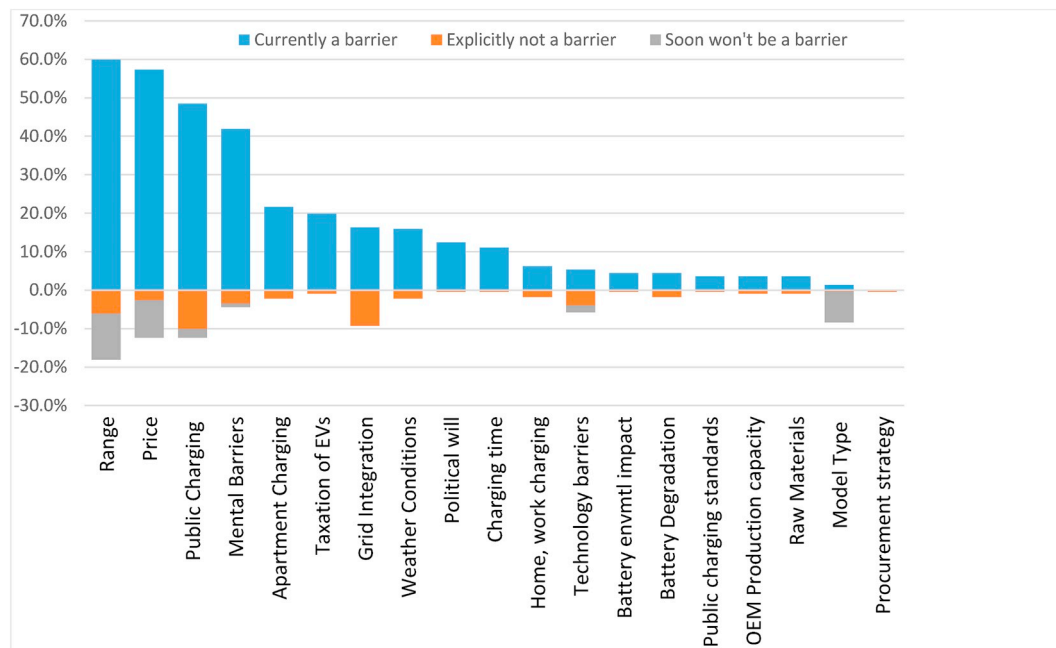


Fig. 3. Barriers and Non-barriers Identified by interviews (only includes topics discussed as both barrier and non-barrier).

Table 3

Differentiation of Barriers by Country, as shown by percent of interviews discussing each barrier. Note that the total n is equal to 222 (not 227) because five interviews did not discuss any barriers to EVs.

Barrier	Iceland (n = 27)	Sweden (n = 42)	Denmark (n = 44)	Finland (n = 49)	Norway (n = 60)	Total (n = 221)
Range	56%	64%	66%	57%	62%	61%
Price	56%	76%	73%	78%	22%	59%
Public charging infrastructure	56%	62%	23%	53%	55%	50%
Consumer knowledge, mental barriers	41%	67%	41%	41%	30%	43%
Apartment Charging	22%	43%	11%	16%	20%	22%
Lack of incentives for consumers	7%	7%	61%	24%	2%	20%
Lack of car models	22%	21%	9%	8%	27%	18%
Impacts to grid	7%	10%	16%	16%	27%	17%
Winter weather	11%	2%	9%	35%	18%	16%
Taxes on EVs	0%	0%	59%	8%	0%	14%

energy/electricity system field both discussed price more commonly than range. More interestingly, those with a transport background (transport system experts/EV industry) discussed consumer knowledge barriers the most, while those with an energy, environment and funding background discussed consumer knowledge the least. Outside of the top four barriers, overall trends also remain mostly similar.

However, one should note that those working more closely to vehicles (Vehicle Researchers and the EV/EVSE industry) discuss the lack of EV car models as a more pertinent barrier, which is less recognized by other groups. Similarly, Vehicle Researchers did not discuss lack of consumer incentives at all, whereas this was a pressing concern for Transport experts/City planners as well as those within the EV/EVSE

Table 4

Differentiation of Barriers by Expertise, as shown by percent of interviews discussing each barrier. Note that the total n is equal to 221 (not 227) because six interviews did not discuss any barriers to EVs.

Challenges	Transport, City Planning (n = 72)	Energy, Electricity (n = 61)	Funding, Investor (n = 10)	Enviro, Climate Change (n = 12)	Vehicle Researcher (e.g. fuel efficiency) (n = 19)	EV, EVSE Industry (n = 34)	Other (n = 13)	Total (n = 221)
Range	74%	49%	60%	50%	63%	56%	69%	61%
Price	68%	51%	60%	58%	63%	56%	38%	59%
Public Charging	47%	56%	60%	42%	37%	47%	62%	50%
Consumer Knowledge, Mental Barriers	51%	28%	20%	33%	47%	53%	62%	43%
Apartment Charging	22%	18%	10%	17%	26%	35%	15%	22%
Lack of incentives for consumers	28%	23%	20%	8%	0%	24%	0%	20%
Lack of car models	18%	11%	10%	17%	37%	26%	0%	18%
Impacts to grid	11%	28%	10%	17%	5%	18%	15%	17%
Winter weather	17%	21%	30%	8%	11%	9%	15%	16%
Taxes on EVs	22%	13%	0%	0%	0%	18%	0%	14%

industry. Clearly, perceived barriers depend on the respondent's particular expertise (or experience), and each expertise's knowledge complement each other, providing a deeper understanding of EV barriers. Finally, from a policy perspective, Table 4 underscores the importance of stakeholder inclusion in the policy discussion and formation process, as well as underscore the importance of unique datasets in academic research (Sovacool et al., 2018a,b). If governments were to act on the basis of discussion from only certain types of experts, the policies formulated in response may accidentally exclude the analysis of other barriers, such as the barrier of model availability in the above case.

3.1. Vehicle range

Range was by far the single most discussed barrier of EVs, brought up by practically 60% of respondents. This issue is exacerbated by the fact that experts saw the long distance of the Nordics, in terms of geographical dimensions and sparsely populated areas, to be one the greatest challenges for transportation in general. Range was commonly acknowledged as being sufficient for most driving, as is also noted in the literature suggesting they are adept for about 85%–98% of drivers, depending on various criteria (Zhang et al., 2015; Saxena et al., 2015; Pearre et al., 2011), but a challenge for the seldom yet very long trips, like when the car is used for a road trip vacation, as R112 describes:

"Then it's about driving distance, if you want to have only one car as private family and you want to go southern Italy on your summer holiday, it's difficult."

Particularly in Finland and Norway, it was also common for the experts to discuss range in context of reaching their summer cottage. As R135 of Finland says:

"Let's say, we are country with long distances. If you just drive around the Helsinki Metropolitan area, that's fine, a range of 40 km is fine. But if you have the summer cottage, or you drive 500 km to your parents, it is not working."

Likewise, R175 connects range to the Norwegian love of nature and reaching their cabins:

"Norwegians are a nature loving country, and our country side is among, we have the mountain range in the middle. So in general people enjoy going to a cabin in holidays. That's when the real challenge are showing up with electric mobility."

Moreover, many experts expected this barrier to continue until EV ranges could compete to various levels of internal combustion engine vehicles (ICEVs). However, the estimate of the necessary increases to the range of EVs were diverse, and appeared to be connected only to comparisons to ICEVs. Some estimates of range were tamer, with experts expecting a range of 300 kilometers to be enough, as R31 proposes:

"So if you get to the border around 300 kilometers on a battery pack, that will be sufficient."

However, the majority of experts believed that the requisite range was substantially higher, somewhere between 400 and 600 kilometers. For example, R6 claims that at 400–500 kilometers range people will begin to consider EVs:

"Then if autonomy of four or five hundred kilometers and the possibility to charge your car – with battery infrastructure, as is being emphasized now, I think people would consider having an electric car as the only car."

R206 adds that once the range of EVs reaches 500–600 kilometers, there isn't a reason for consumers to reject EVs:

"Because when all the electrical cars have a range for 500 or 600 kilometers there is no reason to buy a gasoline or diesel car, so I think the range is the highest priority."

Finally, on the extreme end however, R167 believed that the range needed to compete with diesel vehicles:

"I think the main barriers are still range and the time it takes to refuel. Or a combination of that. Because if you had, like my diesel engine has got 1000 km of range. So, if you had 1000 km of range, it wouldn't be a problem. Or if it only took three minutes to refuel, it wouldn't be a problem you. But I think it is a combination of those."

While many experts recognized that range of EVs only rarely posed a challenge, particularly given the short distances of daily commuting, many still maintained that this was the central challenge. For example, R93 noted that even though they had experience driving EVs and knew it was only a handful of times that range posed any sort of challenge, they still faced range anxiety as a barrier:

"And I know it from myself, it's around 8 times in a year that I drive more than that. But still I have this range anxiety, that 'ohh, do I have sufficient [charge]', right? But it is a limitation."

As a result, some viewed PHEVs as the solution to range anxiety, even if only to cover those few additional trips EVs would not be able to make. Although R76 characterized range as a mental barrier that would only affect a small portion of total trips taken, they still preferred PHEVs as a solution:

"Of course, the negative. You have the range anxiety that I'm sure you've heard a lot of people talk about. But personally I think the plug in hybrids are going to be the gateway to, the stop-gap until we really see electric vehicles. For those people that have the range anxiety, I think the plug in hybrids."

R63 offered another, easy but potentially unpopular solution to this challenge, that is, to rent an ICEV for these seldom trips:

"So, they say 'no that wouldn't work for me because I want to drive to my cabin three times a year. Then, I can't have this car'. But actually then I would argue that you can actually rent a car for special occasions, because you don't need a super car that does everything if you don't use it like that all the time."

On the other hand, in terms of non-private transportation, range was characterized not as a seldom problem, but rather a preeminent one, as R62 notes for heavy transportation:

"But you know the range is the biggest problem. If you want to transport like 40 tonnes on a lorry and you want to get the same range as a diesel lorry, with batteries, the current energy density you would need to fill of 30 of those 40 tonnes with batteries. Long hauling transport, it's a big issue, where electric may not be a feasible option, at least not for the overseeing time."

However, for private transport, the fight seemed to be on focusing extending the range of EVs to mirror ICEVs. Nonetheless, R186 cautioned that continuing the fight to extend range was not only never-ending, but also inefficient (as you would be carrying around extra battery weight), instead the focus should be on adjusting expectations:

"So the discussion for the future is: do you need [that range]. AI guess we will somewhat stabilize on the range about five hundred or six hundred kilometers in the future. But if you're going eight hundred kilometers, that's still not enough [for some. The] next barrier is people getting used to living with it. Understanding it and using the technology right."

Further complicating matters, range was also the barrier that was described by the most experts as *not a barrier*, as 18% of experts explicitly saying it was either not or soon will not be a barrier. The vast majority of these experts, however, viewed range not being a barrier soon, with 12% of experts saying it would no longer be a barrier in the near future, compared to 6% of experts saying it is already not a barrier.

Though these experts believed it wouldn't be a barrier in the future, the time frame was usually relatively short. For example, R28 believed the range issue would be resolved within two years:

"So, I think within 2 years we will have better range in the cars and also we will have the grid completed [referring to EV charging infrastructure]. So, yeah. Two years, there will be nothing stopping people for owning electrical cars."

Similarly, R70 believed that both the range and price barriers will be resolved by 2020 as more OEMs transition to electric vehicles:

"We see that happening right now. But until 2020 it's not going to take off. It's not going to be the market before 2020. We want to see take off with [Tesla] models 3, if they can produce enough cars and meet their goals the model 3 would certainly be big enough and would put a lot more electric cars on the roads. But we need more models and more companies to do this. Luckily, we see that by 2020, VW and Mercedes and all the big companies are coming out will electric cars with a long range at a reasonable price."

However, some of the experts believed that there was no barrier, due to the technical sufficiency of EVs to make the wide margin of trips. As R100 notes, the vast majority of the Danish population would never go beyond further then the range of current EVs:

"I mean, it is cold now, but my Zoe is the new one with the 41 KW battery and I'm doing 200km in this weather [in February] which in Denmark is more than enough for 95% of the population which never goes beyond that. So we have the technology, and there's no barrier in the technology."

Noteworthy, of the experts that did not believe range to be a substantial barrier, they often connected range to the barrier of consumer knowledge and, similarly, experts attached the range element to many of the other 52 barriers discussed; suggesting a nexus of interconnected barriers electric vehicles face as shown in Fig. 2 above.

3.2. Vehicle price

The second most common barrier discussed by experts was price, representing 57% of experts. Price was often an obvious barrier, given that the capital costs of EVs could be often as high as twice the cost of a comparable ICEV, as shown in Table 5. This challenge was compounded by the conceptualization of the EV as a secondary car or an inferior car, due to its perceived technical limitations. For example, R154 articulates that no one would be willing to pay twice as much for less of a car:

"They are too expensive, nobody is going to pay 40,000 euros for second car."

At the same time, it was widely acknowledged by experts that although EVs have a higher capital cost, they also would represent economic savings when viewed from a total cost of ownership (TCO) calculation. But experts believed consumers would not approach the economics of car ownership in this manner, instead, the price tag would dominate decision-making. R14 notes that this is not an uncommon problem in energy, casting EVs as a typical energy efficiency problem:

"Then there is the whole upfront cost problem ... that's a classic problem in energy efficiency policies."

Many experts acknowledged that even if EVs do have a better TCO than ICEVs, this simply would not resonate with the manner in which consumers acted. As R33 notes, people tend to think in terms of capital cost, not total cost of ownership:

"And another is price, they are still quite costly. You have to pay a lot more to get an electric vehicle. If it is more expensive, it is more difficult. People don't think of it in total cost of ownership."

Similarly, R54 adds that it does not matter what a TCO would say because it is incompatible with how consumer conceptualize the economics of vehicle ownership:

"Well, I'm sorry, you've heard this dozens of times before, but the price; it's expensive. And it doesn't matter that it's very much cheaper when you drive it, because that's not how people reason."

Although TCO was widely recognized as a potential benefit, many experts connected the economic aspects of EVs to a type of mental barrier. Compounding the problem, consumer's aversion to TCO is that, as R53 says, consumers will treat EVs and their higher price with increased skepticism because of the emotional connection to ICEVs:

"You need to have a reduction in price to have a lot of sales, but you shouldn't underestimate these social issues. Because cars are a lot of emotional things."

Likewise, R105 suspended their focus on implementing EV, since it wasn't possible for consumer to move past the price tag:

"Right now, we've put it a bit on hold, the electrification of private transportation, because the cars are still more expensive and as long as they're more expensive, we cannot convince people to change."

And even though many other countries viewed Norway as having resolved the price barrier through their plethora of incentives, 11 experts in Norway still maintained price was the primary barrier that the transition to EVs is facing. For example, R171 noted that even in Norway, not everyone can afford the higher-end Tesla:

"You need cheaper cars and of course not everybody can afford a Tesla. So you need cheaper small cars, which you can use for small and low income families."

While it is clear that price is in some ways connected to the consumer knowledge aspects of the nexus (discussed further below), price and range were also correlated with each other. For instance, R50 noted that price was preventing them from buying a car that sufficed their range demand:

"Yea, the combination of price and range ... when I can afford a Tesla, I buy one."

The idea that price and range was a tradeoff between each other was common. R84 added that there needed to be an appropriate concession between the two:

Table 5

BEV and ICEV retail price and range comparison in the Nordic countries. Constructed by authors.

Model	Fuel Type	Price (€)					Range (km)
		Denmark	Finland	Iceland	Norway	Sweden	
Tesla S (75D)	Electric	89,560	102,000	71,000	65,294	92,948	490
VW e-Golf	Electric	41,436	42,551	31,324	34,031	42,073	300
Nissan Leaf	Electric	34,765	35,900	27,676	25,615	35,927	378
Skoda Octavia	Petrol	30,336	23,418	26,566	28,958	20,813	1,020
VW Golf BlueMotion	Petrol	34,093	25,246	26,963	32,656	24,885	1,020
Peugeot 208	Petrol	17,448	15,996	20,143	20,719	15,302	1,022

"The biggest challenge is still price and battery. It's the trade-off of having the price going down while you want the battery capacity to go up. Finding the compromise between those two."

The connection between price and range was the strongest component of the nexus, and many experts listed both price and range, though in contrasting orders. The nexus of range and price also connected to other barriers, such as long charging time, which R127 also demonstrates:

"The biggest barrier about electric vehicles is twofold. First of all, I'm not sure which is the first and which the second, probably the price of the cars, that's the thing. And the second or the first one, is the range, how far away you can go with your car. And that is related also to the question about how fast you can charge the car."

Finally, it is worth mentioning that price also affects the electrification of public transport. When asked about the main barrier for public EVs, R151 said the barrier was the price of not only the bus, but also the related infrastructure:

"Money. It is the main barrier, because it's not just buses which are also rather expensive, but it's also the infrastructure that you have to build."

At the same time, similar to the range barrier, many experts also characterized price not to be a barrier. As shown in Fig. 3, 12.3% of experts believed that price either is already not a barrier or soon would not be a barrier. Unlike range, however, the vast majority of these experts believed that the price would still require some time before it was no longer a barrier. Indeed, R35 believed that the price of EVs would fall to such a degree within the next five years that government should not focus on subsidies, but rather prepare other aspects of the electrification of personal transport, like charging infrastructure:

"So I think if the government decides now to do something, in five years' time, when they actually implement it, it will be too late. And electric vehicles will be cheap enough anyway, and what we really need is charging for them."

Of the few experts who explicitly stated that price was not a barrier, many of them connected it to consumer knowledge and TCO. For example, even in Denmark, where the registration tax system had recently started taxing EVs by 40% (Lambert, 2017), R77 believed that the price barrier was overstated and actually just a misinformation barrier:

"The real challenge may be not so much the price, but that it has been talked about so much. [This has a] negative effect. People believe that electric vehicles are extremely expensive now, which they aren't (although they're still more expensive). So it has had a really great impact that there has been so much negative talking about it, unfortunately."

Indeed while only 2% of experts explicitly stated that price was not a current barrier, many of the other experts did connect consumer awareness and knowledge to how price is viewed as a challenge. Thus, price is connected both to the range and consumer knowledge barriers.

3.3. Public charging infrastructure

The third aspect of the nexus and third most commonly discussed barrier was the need for public charging infrastructure. Compared to the first two barriers there is a slight drop-off in the extent of experts discussing public charging infrastructure, comprising just under half of the experts. Unsurprisingly, public charging was framed as a consequence of the long distances that were common in much of the Nordics. R5 noted that only Tesla had built the infrastructure in the desolate lands in between cities in the Nordics:

"The biggest challenge about electric vehicles is that the charging station are so few at the moment. So the infrastructure is just at the starting point."

So, from here to drive to the north side of the country, it's only Tesla [charging stations]. You don't have anything along the way, unless you have your charging station with you and can go to the next farm and get to charge it for the next two hours or something."

R224 also described the difficulty of providing sufficient charging opportunities in the long distances within Norway that do not have any people:

"It's a problem with infrastructure that we are spread out in northern Norway so much that is hard to expect the charging stations to be all the way to, let's say, Finnmark. That's 7 hours away. I could get to the ferry, the first ferry, but I would pretty much stop after that because I don't think there are any chargers after that. So I need to charge at least 3 times on the road. And that's not how we are used to driving. There are long distances."

In Norway, where EV integration is far ahead of the rest of the Nordics, charging infrastructure was still a challenge, though it was framed as more of a challenge to extend the existing network to meet increasing demand. For example, R175 described a story they had heard about their colleague traveling to their summertime cottage:

"So yes, that's when we will have the charging network constrains. Queues at super chargers today. A colleague of mine told me that 5 EVs were waiting in line for one charger at some point, a few hours up in the mountain ... So if you are the 5th or 6th car coming there and each car is going to use, 30 min, you're 2–3 hours stuck there, and he could observe that people were frustratingly waiting."

Despite many viewed the challenge as simply not having enough chargers available to the public, the solution was not so straightforward. While a simple solution would be to merely build more chargers, many of the experts lamented that the demand for charging was not sufficient enough to encourage this development, resulting in a type of a "chicken and the egg" problem. This barrier was common across all the Nordics. For example R126 described the chicken and egg barrier in Finland:

"So these are the two things and it's a bit chicken and egg problem that everybody talks about. Ideally the cars would be affordable because that would drive the necessity to develop infrastructure and then more private companies would be interested in developing infrastructure."

Norway, where presumably the EV demand would already be present, was not immune from the chicken and egg classification. R218 in Norway still described the chicken and egg impeding the development of charging infrastructure:

"But of course, there is a challenge with infrastructure. And this chicken and egg problem, of course, people want to go wherever they want, and they want to be sure that there is charging infrastructure available."

Finally, the chicken and egg challenge is further complicated by the fact that much of EV charging will occur at home, not at the public chargers, as R39 describes:

"It's like the chicken and egg, which comes first. You cannot have electric vehicles without grid infrastructure, or you cannot have the infrastructure, but you do not use it. They go hand in hand. Then, they find out that 80% of the charging is at home. So, it is not easy to build infrastructures."

Indeed the public charging infrastructure challenge more generally was commonly connected to other parts of the nexus proposed in this paper. For example, R165 characterized price as the primary barrier, but lack of charging infrastructure is the secondary barrier, and also might pose life-threatening danger to EV drivers in Finland:

"The price is number one and then probably the charging network is not yet developed to every city, so that's also something that you need to consider, especially driving during winter. You do not want to go to that

area where you know you are not able to charge and then you are risking your life basically if you are stopped in the forest."

In fact, many of the experts explicitly connected all three technical aspects of the nexus. R58 listed all three as interrelated, particularly range and infrastructure:

"Price and range, and infrastructure. And that is in some way connected with the range, because people think that they drive much longer every day than they really do. And then they think 'my car will run out of electricity and I will be stopped, and there is no infrastructure, so where can I load, where can I charge my car.'"

R93 also connected all three in a nexus, but clarified that charging was the third barrier:

"The price, the range, the limited range that's the biggest two barriers, from the customer as well as the non-customers. And then the charging time also comes, but that's the third biggest because you can get around that. You can plan that. It will give you some limitations but you can get around it."

Beyond the nexus, public charging was also connected to other less common barriers. As an example, R204 saw fast public charging as a way to get around the barrier of apartment charging barriers (discussed more below), which Norway was facing:

"The charging network of course. Fast charging network. If all new car customers should buy electric cars you have to have a much better network than today. It must be fast charging, if you live in areas in Oslo city, you don't have to possibility to charge at home, for many people, then you have to have other choices for fast charging. And today we are not good enough."

On the other hand, as with the previous two barriers of the nexus, there was also a sizeable amount of experts characterizing public charging as not a barrier. However, unlike price and range, which were most commonly designated as barriers that would dissipate in the very near future, it was much more common for the experts to characterize public charging as currently and explicitly not a barrier. As shown in Fig. 3, 12% of experts characterize public charging as not a barrier, and over 80% of those classified public charging as *already* not a barrier, meaning that it did not need time to for the barrier to be assuaged. Most of the experts saying public charging is not a barrier were generally split into two categories; either the current amount of public infrastructure was sufficient, or that public charging was not necessary and was instead a type of mental barrier due to lack of knowledge or experience (Smart and Salisbury, 2015). The idea that current public charging infrastructure was sufficient was particularly associated with Denmark, as R73 notes:

"We have a lot of infrastructure in Denmark, charging points. We have, per each vehicle, electric vehicle we have, I think we have the highest number of charging points. So that's not a barrier."

One reason that Denmark was particularly sufficient in its public charging was that it had the remnants of Better Place, a company that sought to resolve charging networks, as R86 observes:

"It is a bit different from anywhere else. Denmark has the best infrastructure in the world, and it has been done very much on a private base. The reason that has happened is because the company called Better Place, they had a strategy saying okay, just do it. They invested a lot of money and went bankrupt. They had the charge stations that were dismantled, but they also had a lot of charge spots. Those were suddenly for sale and the energy company E.ON bought the system."

Outside of Denmark, the discussion tended to focus on the mental aspects of public charging networks, or that consumers mistakenly believe that they needed public charging to a much greater degree than

they did in actuality. As R11 summarizes, infrastructure demand was a result of mental barriers:

"Infrastructure wise, I don't believe it's the barrier. Mentally it is the barrier, because people think they need to charge everywhere, they think they need posts everywhere."

Similarly, building on personal experience, R216 didn't understand the need for public charging, given the infrequency of which public charging was necessary:

"I don't understand that really. I have had my EV for one year and I think I've fast charged my car two times. And I am driving 15,000 kilometers on a yearly basis."

Thus, the public charging barrier may be borne out of consumer inexperience with EVs and undervaluing charging that may occur at home or work. Lastly, though many experts believed public charging was already not a barrier, only five experts discussed public charging in context of soon not being a barrier. Most of these were either in context of the buildout constraints of developing the entire charging network, or in tandem with new EV models increasing range.

3.4. Consumer knowledge and experience

To round out the top four most common barriers and complete the proposed nexus, the next most discussed barrier focused on the consumer: either their lack of knowledge or experience, or other mental barriers. And unlike other aspects of the nexus (e.g., public charging infrastructure, which was commonly described as secondary to other barriers) consumer knowledge was more prominent in the discussion of barriers. To many experts, consumer knowledge was the primary barrier to EVs, as R104 who put it succinctly:

"The biggest barrier in Denmark is the mental barrier."

Correspondingly, for R66, consumer information and experience is the number one priority for transport policymakers working on EVs:

"I'd say, the number one barrier that transport people should focus on, is perception. There is still a view that it's all really nice, but not for me. So, we need to work with information and customer acceptance and testing opportunities."

Likewise, lack of EV knowledge allowed myths to continue to persist in Norway, in spite of their strong support of EVs, as R177 of Norway documents:

"And we see that there is a huge need for good information, correct information. There are a lot of myths when it comes to the batteries: people think they are toxic, people think they are, you know, going to break easily, that you need to change batteries every four years There are a lot of misconceptions related to EVs basically."

However, more importantly, and as hinted in the discussion above of the nexus between range-price-public charging, experts commonly connected the nexus to consumer knowledge and experience, claiming these technical barriers were actually rooted in mental barriers. Nearly all of the discussion of consumer knowledge and experience focused on the three technical aforementioned aspects of the nexus. First, for many experts, range was not actually a technical barrier, but rather was a knowledge and experience barrier, given that EVs could suffice the vast majority of the average trips an average resident in the Nordic countries would take (Liu et al., 2015). As a result, R93 pointed out that this mismatch between technical sufficiency of range and subsequent range anxiety was a result of consumer ignorance:

"And people, that's another, people don't know the possibility of doing the charging at home. People don't know that 92% of all trips can be done by

the range of a normal EV. So the car is also a symbol for freedom in our part of the world. And then there is a knowledge gap."

The idea that EVs could meet over 90% of daily driving demands was often brought up by experts when discussing the connection between range and mental barrier aspects of the nexus. Adding to this, R31 also connected to lack of knowledge to range as well as winter weather implications on range:

"So, I think the important thing is people's mentality. Because 95% of all the distances people are driving per day in Europe, not just the Swedes or Norwegian or Danish, is 50 kilometers a day. Any electrical car that existed from 2009 and forward has made that. So, it's not that big of a problem even in the Scandinavian winter climate."

Finally, the mental barriers regarding range may be difficult to resolve. As R45 recognized in their experiment of giving people an EV to use, consumers still saw range as barrier despite experiencing the EV sufficing their daily travel demands:

"Yea, there could be prejudisim about it. It could also be a barrier that is much more connected to experience: of thinking that you need more range than you actually do. Even in our experiment, [the participants] see range as a limit [even though] they manage with the range they get – we had an e-Golf, which practically got around a hundred and thirty kilometers, even if it's stated as more. They never had any problem, they managed all the trips, but they still wanted more range."

Moving onto the second aspect of the nexus, the price barrier was also seen as a result of consumer mental barriers, typically focusing on lack of consumer knowledge. R25 noted that consumers in Iceland tended not think rationally when it came to realizing economic savings from a TCO perspective:

"It's hard to say maybe, I'm going to say it though [I'm] insulting the entire nation. We are not the smartest consumers, we just go for things. So sometimes it's hard to introduce things that have a payback time."

This is not an issue specific to Iceland or the Nordics, indeed, it is typical for consumers to highly discount future savings (Allcott and Wozny, 2014; Hausman, 1979). Exacerbating this issue, some experts believed that because consumers were generally distrustful of EVs, consumer would not even believe the idea that the TCO of EVs is lower (much less discount properly), as R32 describes:

"The electric motor is more economic to drive itself. I drive an electric car since a year and a half, and I have never had so cheap a car. But it's hard to explain to people. They don't believe in it yet."

On the other hand, while experts noted various issues with consumer awareness and the economics of EVs, other experts believed that price was not very influential on consumer behavior. As R89 illustrates, EV deployment might not depend on consumers understanding TCO in the face of a higher price, but rather the fashionability of EVs:

"So it's not within the money, the money is not the problem here, I think. [Because] even when it comes down to electrical cars, it's very much down to fashion and perception. And now the minute it gets fashionable to drive an electrical car [snaps fingers], it can cost a lot."

Regardless of how relevant price and TCO are to an EV implementation, it is clear that there are to some extent mental barriers that affect consumers' willingness to purchase EVs or even their willingness to consider EVs.

Thirdly, experts also connected consumer knowledge and experience to the public charging infrastructure barrier. In this case, most of the experts attributed consumer ignorance to the perception that public charging infrastructure was an impediment, often connecting the technical sufficiency of EV range and availability of home charging, as R29 describes:

"But you know, 95% of all the EVs owners in Iceland, they charge at home only. 95% of all the charging, they do at home. But it's a mental state, you know, you need to see [public chargers] everywhere, or otherwise I can't buy a car."

As a result, many experts believed that the focus should be on developing home and work charging instead of high power public charging. For example, R45 believed that home and work charging infrastructure was more important, but recognized people still felt they needed public charging as "insurance":

"I think when it comes to charging infrastructure the two most important places are the homes and the work place. And once you have those, you cover quite a lot. But at the same time, people, you know when you talk about this in a lot of interviews with people, they want more charging infrastructure. But then the question is how much should they actually [need]. It's like charging is kind of an insurance. You feel that you want it, but you're probably not going to use it that much."

Moving beyond the nexus, consumer knowledge also affected how consumers viewed the benefits of EVs. Indeed, R52 blamed the consumer skepticism and lack of knowledge of modern EVs on the first EVs that were ridiculed as inadequate:

"And people have been skeptical to electric cars, as just a couple of years ago the electric cars were quite primitive. I mean, our first cars were these Norwegian Thinkers. A brand that ultimately disappeared. And they are like Donald Duck cars, plastic things. It's like a joke. So, that's the mental view people have been having."

As a result, many experts believe that experience with modern EVs is vital to educating people of the benefits that EVs can offer. Such experience can help shatter preconceived notions of what consumers believe an EV is. The surprising benefits of EVs leaves consumers with what R33 calls the "EV smile":

"People talk about the EV smile that happens when you have driven an electric vehicle for the first time and come out with a smile on your face. Everyone talks about that. In the EV world, it's something you are aware of, and that's what happens."

While experience is key to educating consumers about the benefits of EVs and both information and education may be necessary to properly characterize the technical aspects of the nexus, it was noted that mental barriers may be the most difficult to resolve. As a result, R98 believed a reduction of consumer's mental barriers will likely lag behind technical improvements to the range-price-charging nexus:

"I think the technology will run faster than the mentality of people will change. So, I think the solution will be that the batteries are actually getting better. Even though you are completely right. But I think it takes a shorter time to develop the technology than it takes to change the mind of people."

3.5. Other prominent barriers

Moving beyond the four most frequent barriers, each of which were discussed by at least 40% of the experts, there were seven additional barriers that were discussed by at least 10% of the experts: apartment charging, lack of consumer incentives, lack of car models, grid integration, winter weather, lack of political will, and long charging time.

Charging infrastructure for townhouses and apartment complexes was discussed by just over 20% of the experts. Unlike the other more technical aspects of the nexus discussed above, there was limited connection between apartment charging infrastructure and mental barriers. Similarly, less than 15% of experts discussed apartment charging in the context of EV's range, making it far less connected to the nexus than most other barriers. Many experts believed that resolving

apartment charging would be very difficult as it relies on other stakeholders, as R35 notes:

“The biggest barriers are people living in apartments. If you own your own house, you have no problem at all, but if you live in an apartment, you need to get the house-owner to install the charging station. And that has been extremely difficult.”

Worse yet, apartment charging is not a niche problem, as R69 noted that a large subset of the Swedish population is living in apartments:

“I think one thing that we didn’t talk about concerning the infrastructure, in Sweden, it’s fifty percent of people live in apartment buildings, they don’t necessarily have access to their own parking spot, and I think that’s something we have to address.”

Finally, there were social aspects of apartment charging. R136 discussed that apartment charging also raises questions of equity and could even lead to fights:

“I have heard rumors that there are actually big fights, because somebody has an EV and then the other ones of course say - we are jealous people here in Finland - ‘no you cannot charge your vehicle here because there are no rules for how to do it, we don’t want to pay for your charging’.”

While apartment charging was not as widely discussed as the four central barriers, there was also not as much hope that it would be resolved within a short time frame, like range and price could be. And unlike the other three technical barriers discussed, it is unlikely that better information and education of consumers would reduce the perception of this impediment. For these reasons, apartment charging might be the most persistent barrier in the near future of EVs.

For many of the remaining technical challenges, range permeated throughout. For example, R64 described their personal challenges using their company’s EV both as a result of the long charging time and the lack of range:

“Sometimes when we have customer visits that might be 150 kilometers away you wouldn’t take that car. So, there are limitations as well. Even if we know there is a charging station halfway, we still won’t take it, because that is too time consuming. Time is always an issue.”

Similarly, winter weather was frequently discussed in the context of its impact on range, with half of the experts explicitly connecting winter weather to range. For example, R1 noted that range was particularly a challenge in Iceland when temperatures reached below zero and reduced the range by more than 50%:

“But then still we have a few days that it is minus five to minus ten, but that’s only 10 days of the years or something like that, and when it happens the EVs that are supposed to be 250 kilometers go 150 or 100. So that’s an issue.”

Likewise, in Finland, R151 connected range and public charging infrastructure to how winter limits range for long holiday car trips:

“The range of the electric vehicles is not enough, especially in the winter time, if you want to go for a holiday in Lapland. You don’t have charging stations and then it maybe minus twenty, thirty, forty even, so it’s a bit challenging.”

Next, it was common for experts to suggest that the biggest barrier was the lack of government action to provide consumers with incentives to purchase EVs. Lack of consumer incentives was suggested as a barrier by nearly 20% of experts, while lack of political will was submitted by 12%. Of the 45 experts who discussed the lack of consumer incentives as the central barrier to EV adoption, about 60% were from Denmark. The next most was Finland, with 12 experts discussing lack of consumer incentives as a barrier. The remaining 6 experts were split into Iceland, Sweden and Norway. While the magnitude varied across the Nordics,

nearly all experts who discussed lack of consumer incentives focused on the lack of subsidies to reduce prices either by reducing registration taxes or annual car taxes, particularly outside of Norway. Only 2 out of the 45 experts connected the lack of consumer incentives to the secondary benefits, i.e., free parking, tolls, driving in the bus lane, etc., implying that price was perceived as much more important dimension than other consumer incentives.

It was a very similar story regarding the lack of political will, which was likewise very regionally disparate. By far the most experts, again nearly 60% of the 28 total experts, were from Denmark, who had recently removed the exemption to EVs, increasing the registration tax to 40%. Correspondingly, practically all the discussion in Denmark focused on the complexities of the registration tax scheme, and the political risk that increasing ICEV costs would entail to subsidize EVs. Finland comprised the second most common country, with 7 experts claiming that the lack of political will was a major barrier to EVs. The government inaction in Finland was attributed to the powerful biofuel industry, implications that the government did not want to favor EVs over biofuels, and as well as general EV inexperience, particularly on a city level. The remaining 5 experts were from Iceland, Sweden and Norway.

Finally, the remaining barrier was the impact of charging on the grid. Though this issue returned in all the Nordics, it was most commonly discussed in Norway. Nearly all the discussion was focused on distribution networks. R213 describes that the challenge isn’t the total amount of energy EV charging requires, which was generally seen as minimal, but rather providing the power through weak distribution networks:

“We have enough electricity, that is no problem. But you can have, you know, problems with the distribution network and such.”

Interestingly, the grid integration issue was split, as for every two experts who believed it was a barrier, there was one expert who believed it was *explicitly not a barrier*, see Fig. 3. This remained true across the countries, as there was a near-mirrored distribution across the Nordics for both those experts who said it and those said it was not a barrier.

Beyond these common barriers there was still a remarkable list of 42 other challenges discussed. Many of the remaining barriers, though not widely discussed, focused on the techno-economic aspects of EVs, like various issues related to batteries (lifetime, recycling, production) or challenging business models and electricity taxation. It is worth to note that, curiously, 9 experts believed that there were no explicit barriers to EVs, and an additional 10 believed that the only barrier was time. But of those 19, only 8 were not from Norway. Stated another way, of those who did not believe there to be a substantial barrier to electrification, ~60% were in Norway, where the government has taken substantial steps to address the barriers to EVs.

4. Conclusion & policy implications

Indubitably, even in the Nordic region EVs face a wide variety of barriers, though much of the focus both in the literature and by the experts interviewed emphasizes range, price, charging infrastructure, and psychological factors. It is undeniable that there are true techno-economic aspects behind the nexus of range-price-charging; the range is certainly less than an ICEV, the price tends to be higher looking only at the sticker, and there are far more gas stations than public charging infrastructure. However, a closer look at this nexus will reveal that these barriers proposed by the experts we interviewed are more deeply rooted in sociotechnical dimensions such as consumer knowledge and experience.

For instance, range is technically sufficient for well over 90% of trips taken by Nordic drivers (Liu et al., 2015; Pearre et al., 2011), but consumer acceptance of transitioning to a vehicle that is incapable of providing *all* trips remains a substantial barrier, regardless of potential

solutions or the infrequency. Similarly, public charging, which is very rarely used in day-to-day use of EVs (Smart and Salisbury, 2015), correlates to consumers' perceptions of range. And for price, it is clear that consumers focus on capital cost of vehicles rather than on the total cost of ownership calculations, which favors ICEVs despite not being the least-costly option in the medium to long term. A key aspect, is the irrationality of private individuals over discount rates (Allcott and Wozny, 2014; Hausman, 1979), which could play a central role in the transition to electrification. Consumer perception and understanding of personal vehicles are at the core for reducing the impact of the nexus of technical barriers moving forward, and thus foster increasing deployment of electric vehicles internationally. Future research should not only recognize these inherent links between the technical and non-technical elements, but also work to understand the dynamics of interconnectivity amongst the barriers of the nexus.

While the techno-economic aspects of the price-range-charging nexus are expected to decrease mostly in the near future, the prevalence of mental barriers may imply that there will be a lag between the diminution of technical barriers and the time when consumers have the knowledge and experience requisite to choose EVs as their primary or solely mobility option. Given the nexus of barriers, the implication for policy making is that EV policy should not focus on a single barrier, but rather use a set of tools to address the nexus to resolve the social roots of the various technical challenges. Thus policymakers should carefully consider any policy that addresses this nexus in the context of the consumer knowledge and experience barriers. As an example, many experts viewed developing a comprehensive charging network as very expensive – this may be especially true if an alternative is a low-cost consumer information campaign realizing that a comprehensive public charging network is not as necessary as it is commonly believed (Smart and Salisbury, 2015). Indeed, giving information and experience to consumers may be a cheaper alternative while also being more effective than resolving to a techno-economic policy approach. Additionally, it is also important to note that the proposed nexus does not only cover users of private vehicles, but also fleet owners and public transportation operators. As such, fleets and public transportation electrification policy should also acknowledge the interconnected nature of the EV barriers nexus.

Consequently, EV policy should take a more comprehensive approach by borrowing concepts from the extant literature on sustainability and policy mixing (Rogge et al., 2017; Kern and Howlett, 2009). The complexity of the nexus of sociotechnical barriers discussed above arguably requires a more comprehensive approach of combining policy processes, elements and characteristics to develop a consistent and coherent EV policy mix (Grubb et al., 2017; Rogge and Reichardt, 2016). Framing EV policy within the framework of policy mixing may better address the interconnected nature of the barriers, as well as make

transportation policy more coherent with sustainability policy in general. Future research should examine the role of designing policy mixes, using the nexus proposed here as a potential starting point, similar to other case studies of comprehensiveness in policy mixing (see e.g., Rosenow et al., 2017).

Finally, though our work implies that consumer knowledge and experience lie at the roots of many of the perceived technical barriers, there are some barriers that appear to be mainly technical, like apartment charging solutions. However, apartment charging too faces social resistance by way of skeptical housing authorities. Additionally, while numerous experts agree that the technical aspects of the nexus (range-price-charging) will be resolved within a short time frame, such solutions are not readily apparent for apartment charging. Thus, to the extent policymakers wish to invest in charging infrastructure, our results imply that home and work charging, particularly for those living in apartment complexes, should be favored over public charging networks.

Moving forward, this paper calls for further research, policy development and decision-making to recognize the dynamics and relationships among the plethora of barriers that electric vehicles face. The temporal aspect of some of these barriers should be studied to understand how the near-future reductions of barriers will impact the adoption rate of EVs. Also, future research should certainly be undertaken in order to understand how the nexus, as described by experts, compares and contrasts to a consumer perspective. We have demonstrated that EV barriers are not solely based on either technical or non-technical elements, nor do they operate in isolation. As the quest for decarbonizing transportation continues, and electric vehicle technology becomes more prominent, policymakers and researchers should continue to explore the interrelated (and constantly evolving) nature of this nexus.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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A. Appendix I – Overview of Semi-Structured Research Interviews

Table A.1
Overview of Semi-Structured Research Interviews

Country (5)	Cities (17)	Interviews (227)	Visit (9 months)
Iceland (n = 29)	Reykjavik	1-22, 29	Sept/Oct 2016
	Akureyri	23-28	Sept/Oct 2016
Sweden (n = 42)	Stockholm	30-43, 66-68, 70	Nov 2016
	Gothenburg	44-61	Nov 2016
Denmark (n = 45)	Lund and Malmo	62-65, 69, 71	Nov 2016
	Other ^a	72	Jan 2017
	Greater Copenhagen Region	73-100, 113, 115	Jan/Feb/Mar 2017
	Aarhus	101-102, 104-107	Feb 2017
	Other ^a	103	Feb 2017
	Aalborg	108-112, 114, 116	Feb/Mar 2017

(continued on next page)

Table A.1 (continued)

Country (5)	Cities (17)	Interviews (227)	Visit (9 months)
Finland (n = 50)	Greater Helsinki region	117-144, 154, 163	Mar 2017
	Tampere	145-153, 155, 164	Mar 2017
	Oulu	156-162, 165-166	Mar 2017
Norway (n = 61)	Greater Oslo region	167-208	Apr 2017
	Trondheim	209-220, 222	May 2017
	Tromsø	221, 223-227	May 2017

^a Two Danish towns are not mentioned by name for anonymity of interviewees.

Table A.2

Summary of Experts Participants

Classifications	Interviews (n = 227)	Respondents (n = 257)	% of Respondents
Country = Iceland (Sept–Oct 2016)	29	36	14.0%
Country = Sweden (Nov–Dec 2016)	42	44	17.1%
Country = Denmark (Jan–Mar 2017)	45	53	20.6%
Country = Finland (Mar 2017)	50	57	22.2%
Country = Norway (Apr–May 2017)	61	67	26.1%
Gender = Male	160	207	80.5%
Gender = Female	40	50	19.5%
Gender = Group	27		
Focus = Transport or Logistics	73	81	31.5%
Focus = Energy or Electricity System	63	75	29.2%
Focus = Funding or Investment	10	12	4.7%
Focus = Environment or Climate Change	12	16	6.2%
Focus = Fuel Consumption and Technology	22	23	8.9%
Focus = Other	13	14	5.4%
Focus = EVs and Charging Technology	34	36	14.0%
Sector = Commercial	68	70	27.2%
Sector = Public	37	46	17.9%
Sector = Semi-Public	40	51	19.8%
Sector = Research	37	39	15.2%
Sector = Non-Profit and Media	12	13	5.1%
Sector = Lobby	23	25	9.7%
Sector = Consultancy	10	10	3.9%

Source: Authors. Focus represents the primary focus area of the organization or person in question, sector represents the sector the company was working in (semi-public referring to commercial companies owned by public authorities, like DSOs).

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